# Distributed Route Aggregation on the GlObal Network (DRAGON)

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# Last year in the news (August 2014)

THE WALL STREET JOURNAL. ≡ TECH

TECHNOLOGY

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Routers That Send Data Online Could Become Overloaded as Number of Internet Routes Hits '512K'

By DREW FITZGERALD CONNECT

Updated Aug. 13, 2014 7:38 p.m. ET

BBC News Sp

NEWS TECHNOLOGY

**14 August 2014** Last updated at 12:05 GMT

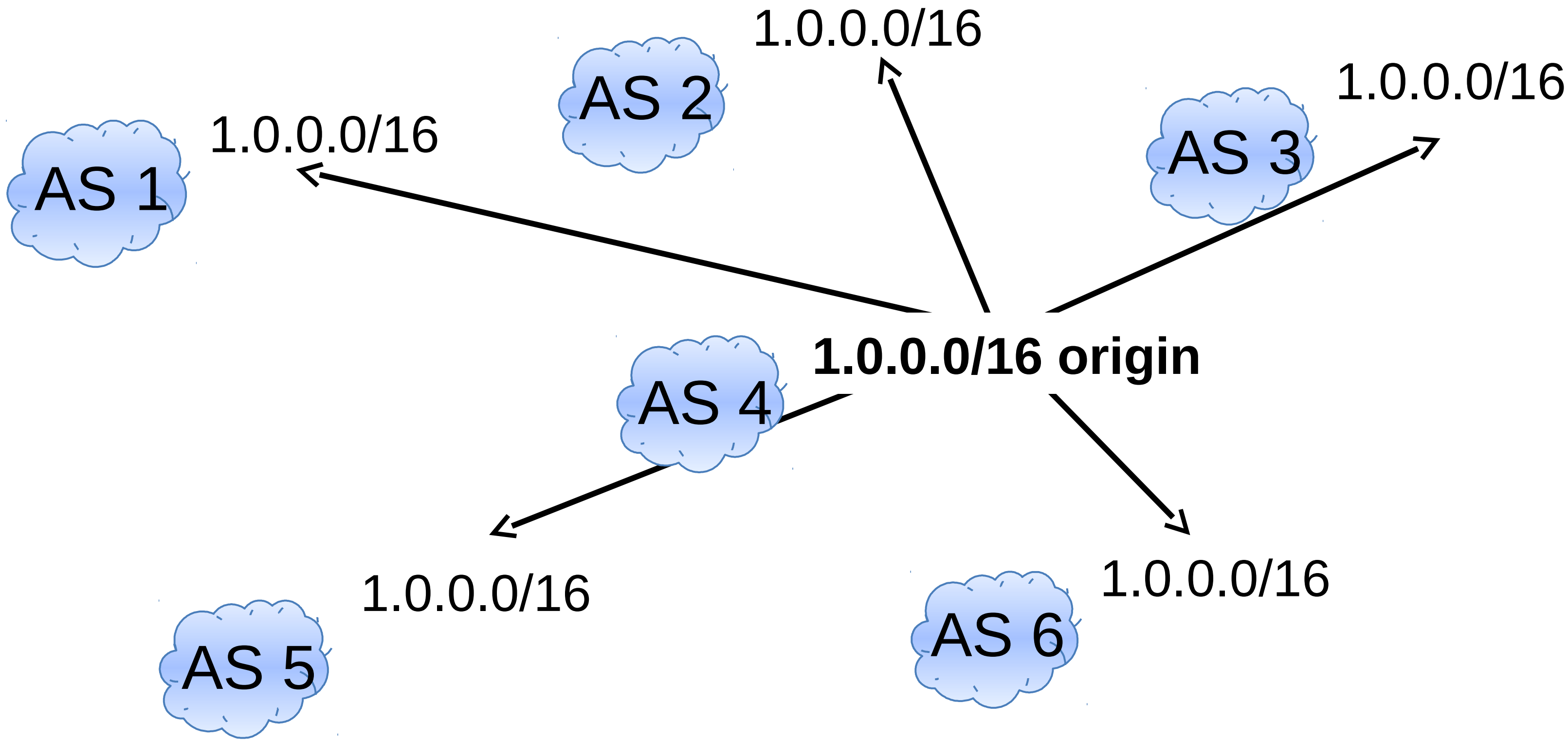
## Browsing speeds may slow as net hardware bug bites

**By Mark Ward**

Technology correspondent, BBC News

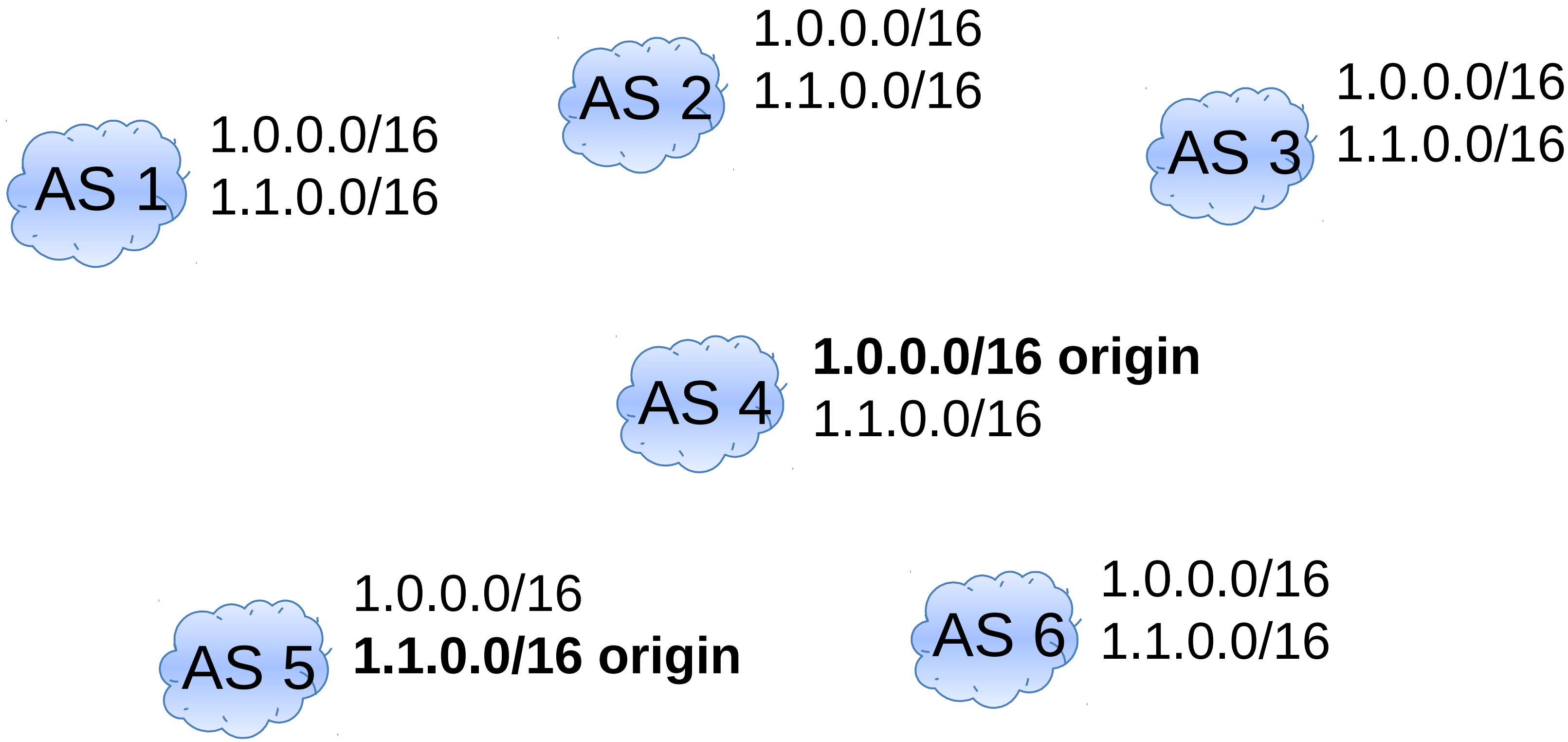
**Some routers could not process the +512 K IPv4 prefixes they were learning about**

# Not a scalable routing system




**Most of the originated prefixes are routed globally (by BGP)**

# Not a scalable routing system

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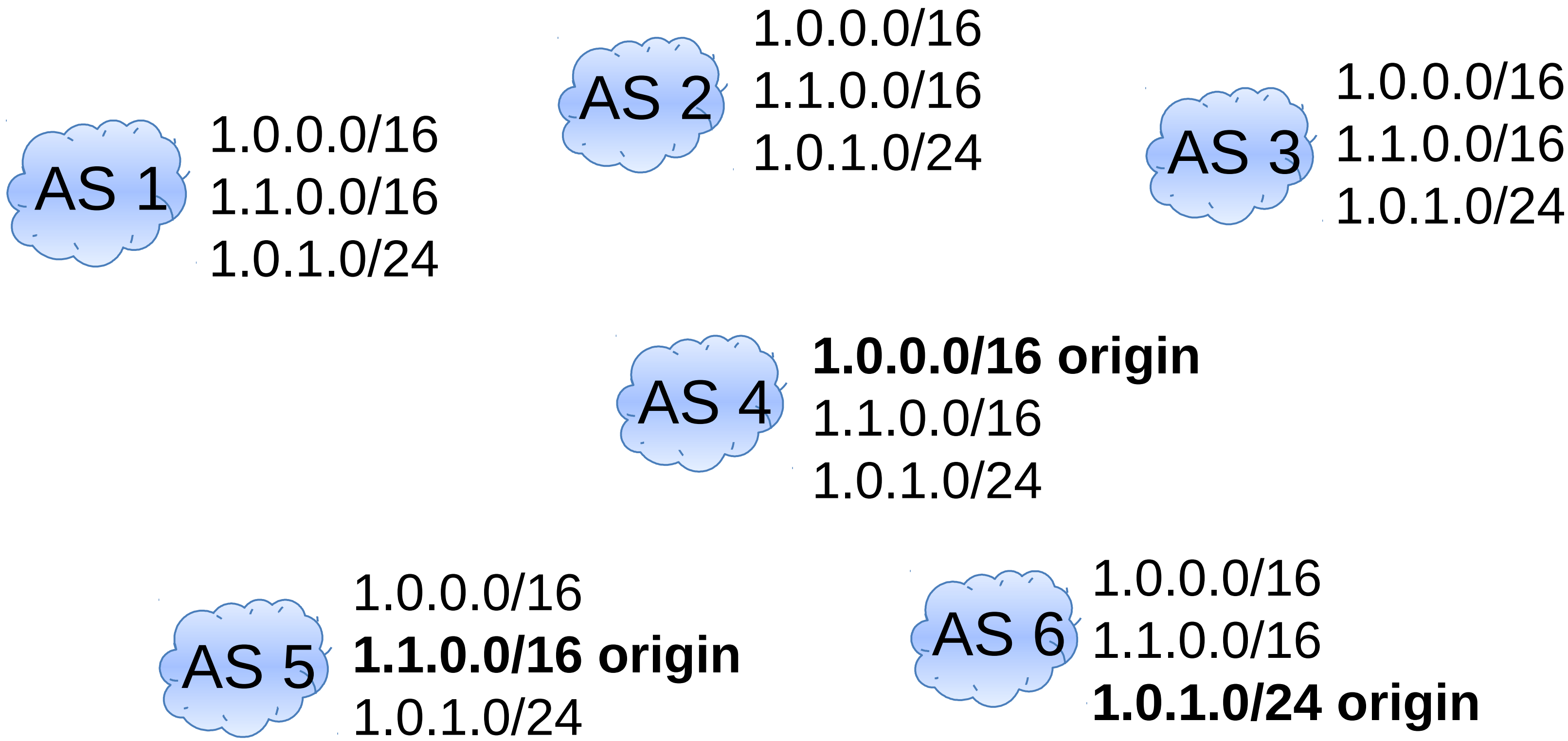


**Most of the originated prefixes are routed globally (by BGP)**

# No scalability: poor performance

- Forwarding tables (FIBs) growth & address look-up time increase
- Routing tables (RIBs) growth
- BGP session set-up time increase
- Churn & convergence time increase

# Further scalability concerns

- IPv6 prefixes can be formed in potentially larger numbers than IPv4 prefixes
- Secure BGP adds computational overhead to routing processes

# DRAGON

Distributed solution to scale the Internet routing system

**Basic DRAGON**: **49%** savings on routing state

**Full DRAGON**: **79%** savings on routing state

*No changes to the BGP protocol*

*No changes to the forwarding plane*

**Readily implemented with updated router software**

# Outline

- Scalability: global view
- DRAGON: filtering strategy
- DRAGON: aggregation strategy
- DRAGON: performance evaluation
- Conclusions

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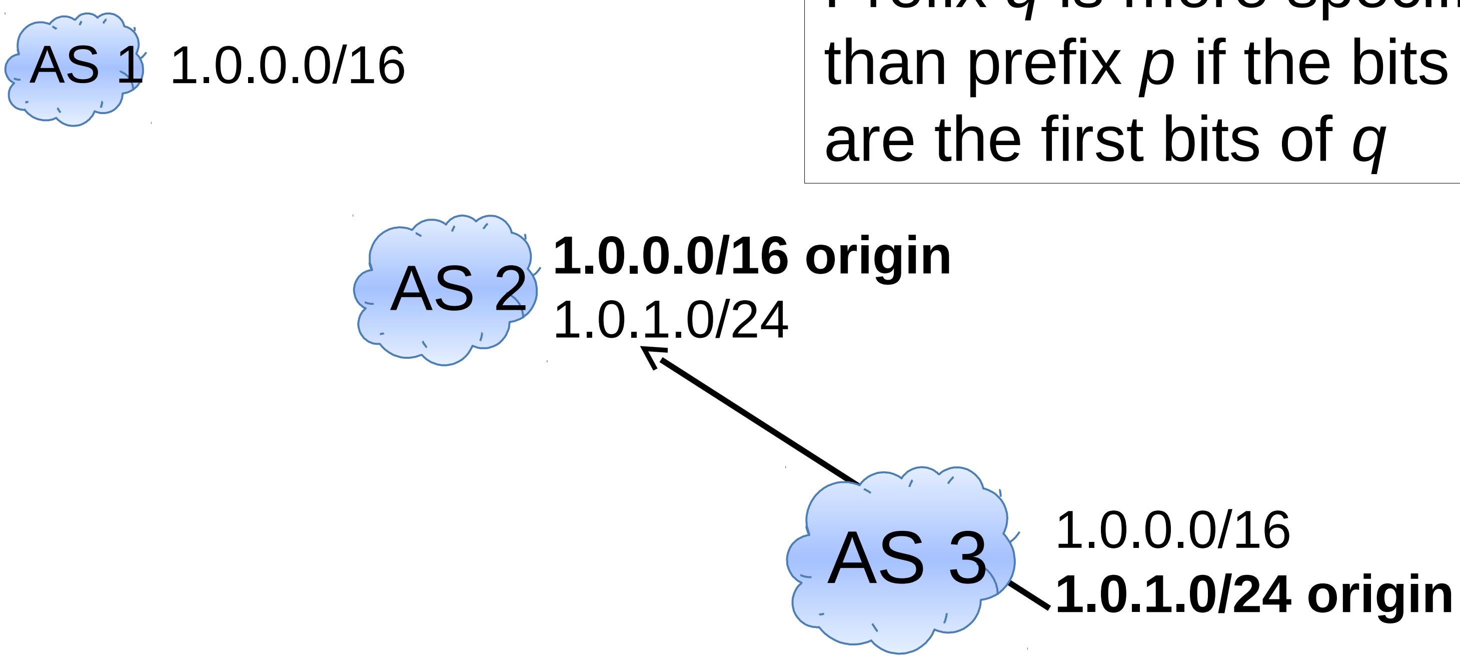
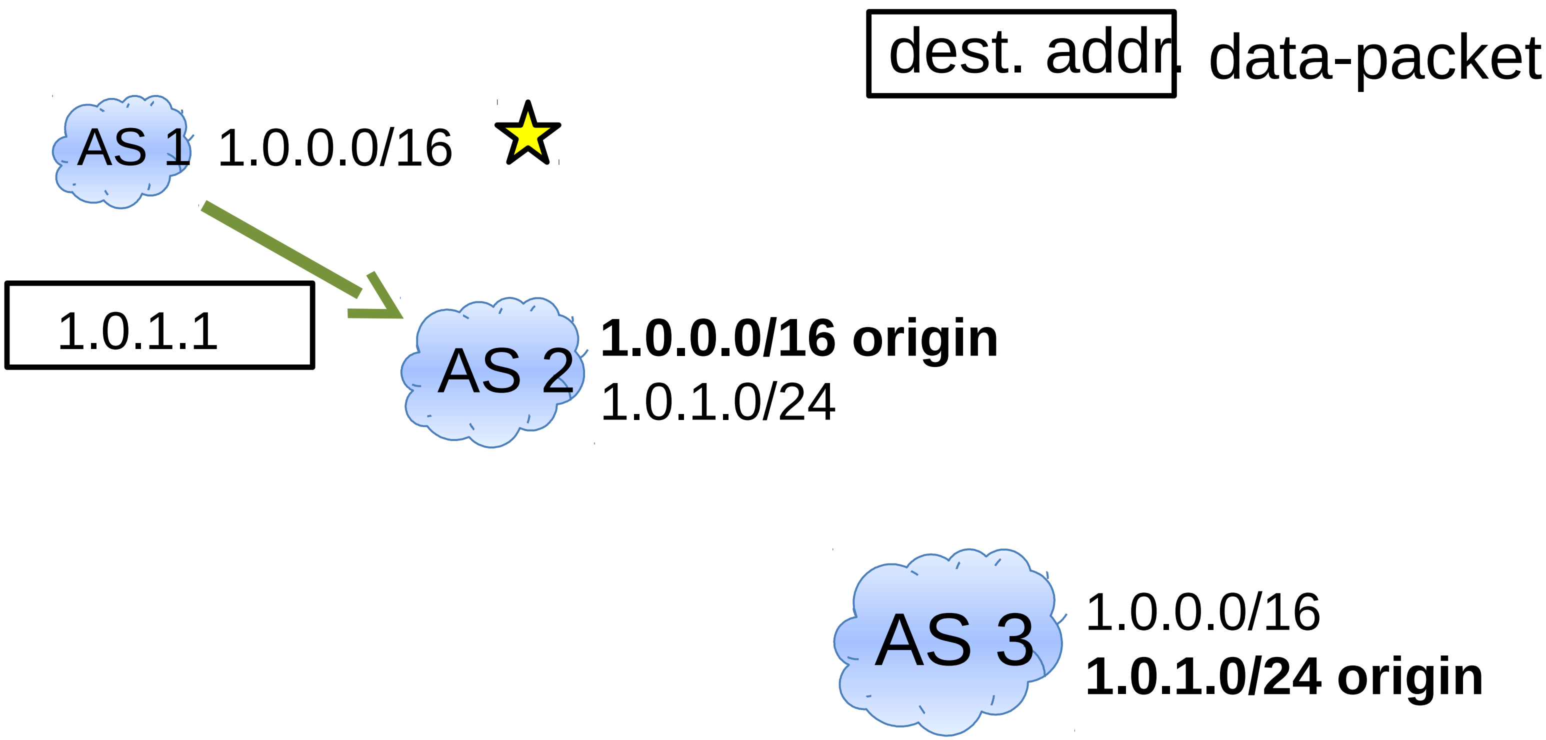
# Scalability: global view (routing)

**Specificity**
Prefix *q* is more specific than prefix *p* if the bits of *p* are the first bits of *q*



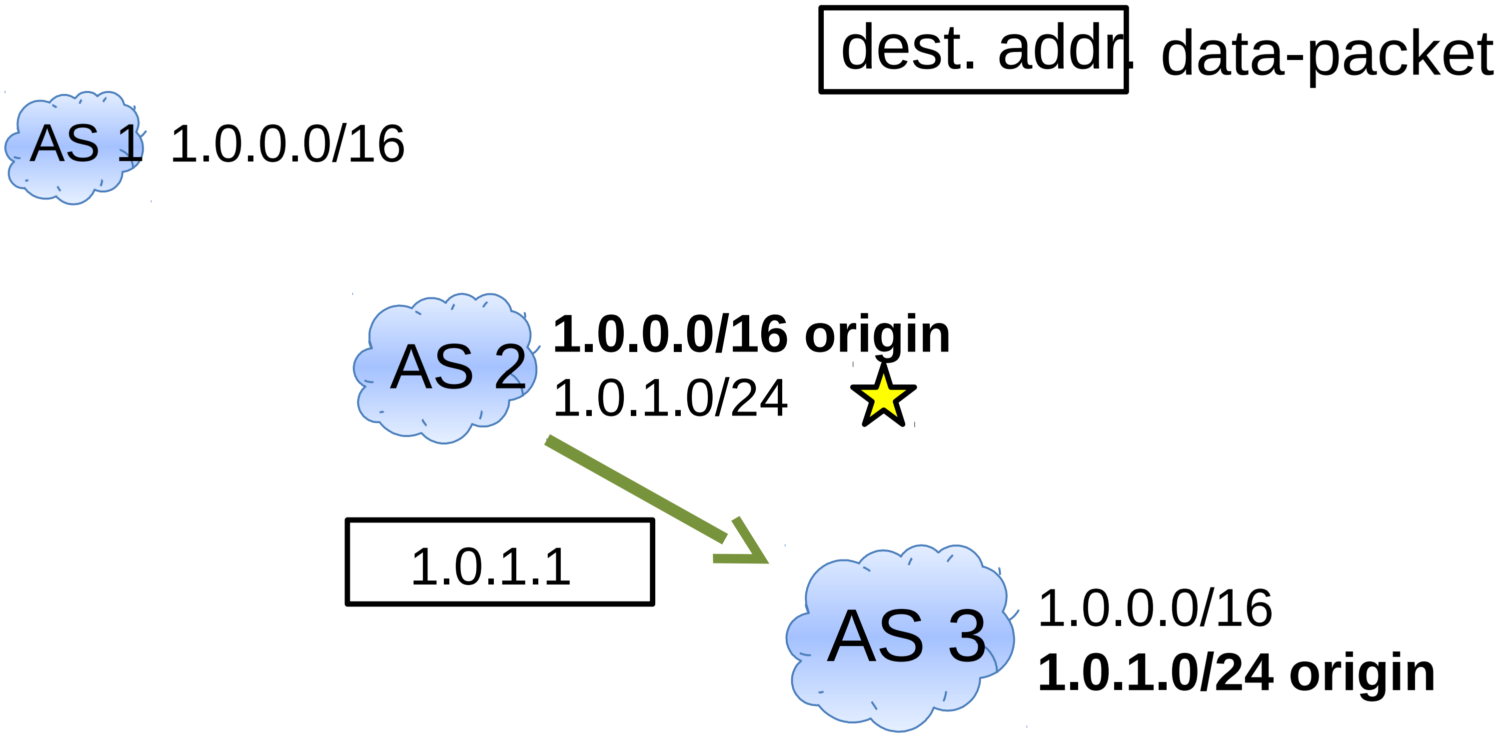

**Propagation of more specific prefixes only in a small vicinity of their origin ASs**

# Scalability: global view (forwarding)

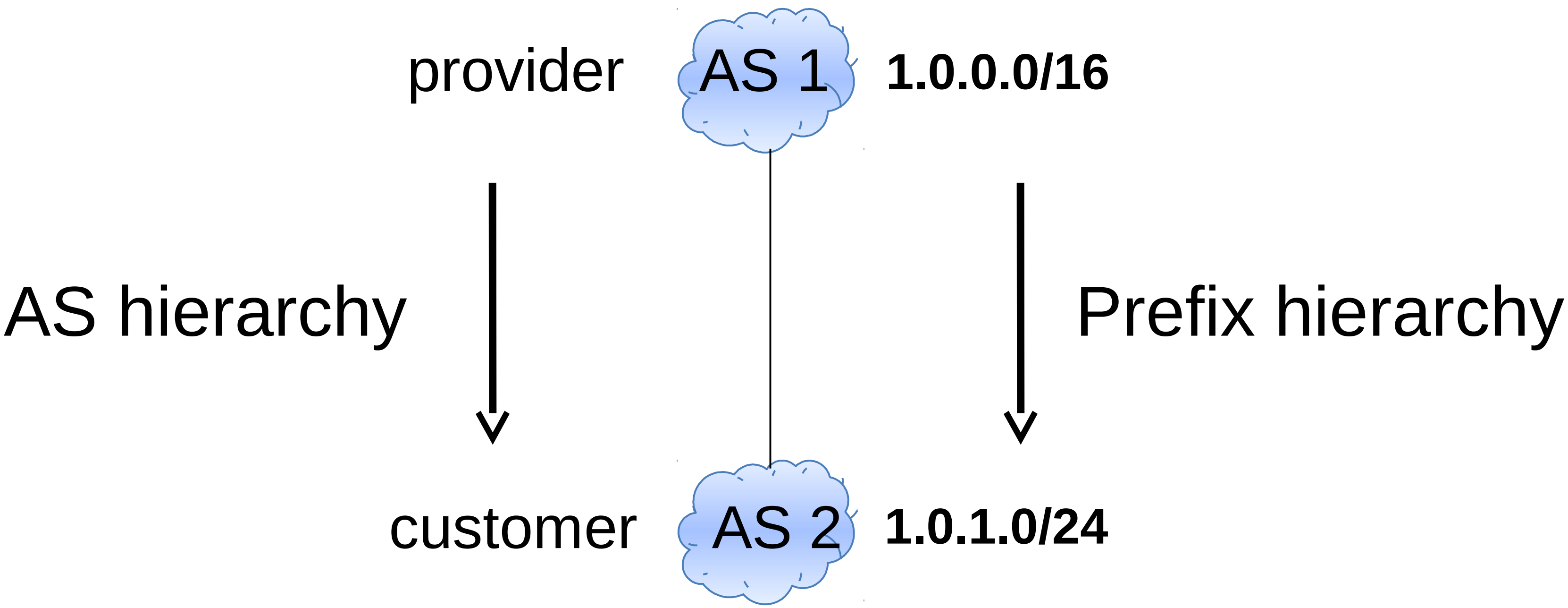



**Most ASs forward data-packets on the (aggregated) less specific prefixes**

# Scalability: global view (forwarding)

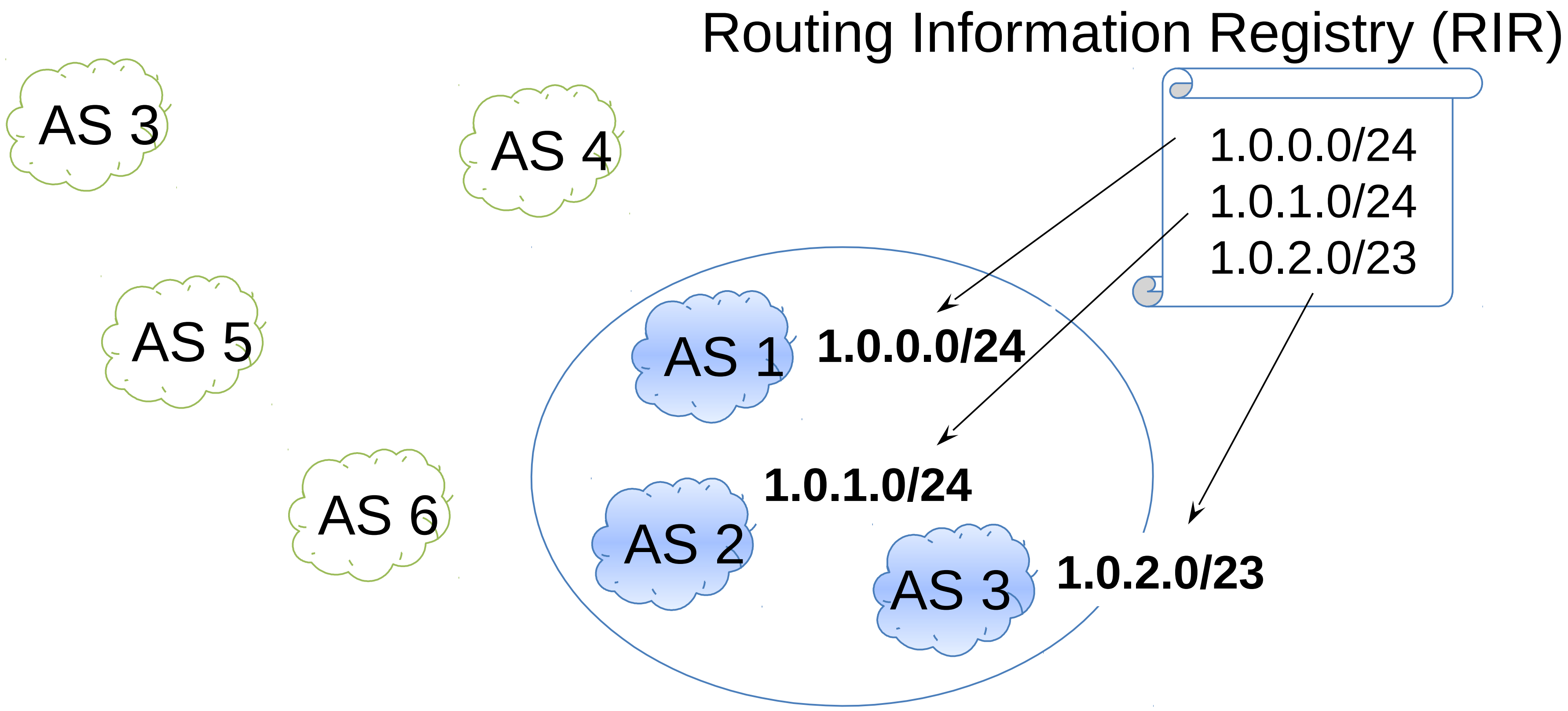


# Hope for scalability? Hierarchies




**AS-hierarchy aligned with prefix hierarchy**

# Hope for scalability? Clustering




1.0.0.0/24 + 1.0.1.0/24 + 1.0.2.0/23 = 1.0.0.0/22

**Geography *roughly* clusters together ASs with aggregatable address space**

# Challenge: global vs. local

**How to realize the global view through automated local routing decisions?**

*especially, given that the Internet routing system is as decentralized as it can be:*

- each AS decides where to connect
- each AS decides where to acquire address space
- each AS sets its own routing policies

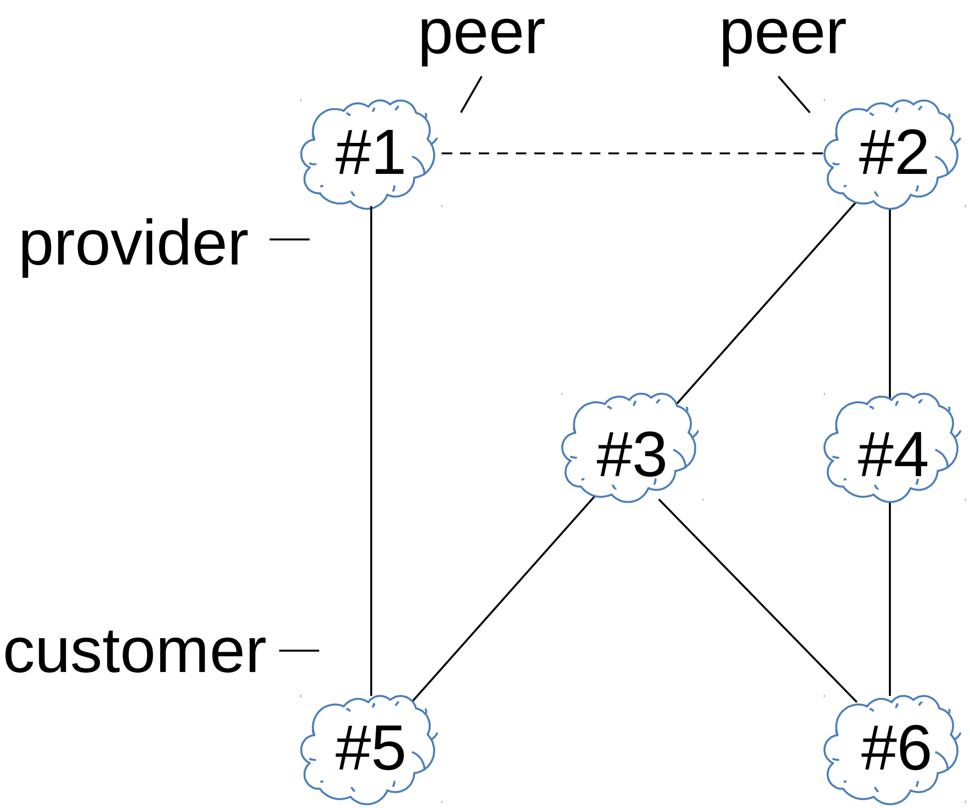
# Outline

- Scalability: global view
- DRAGON: filtering strategy
- DRAGON: aggregation strategy
- DRAGON: performance evaluation
- Conclusions

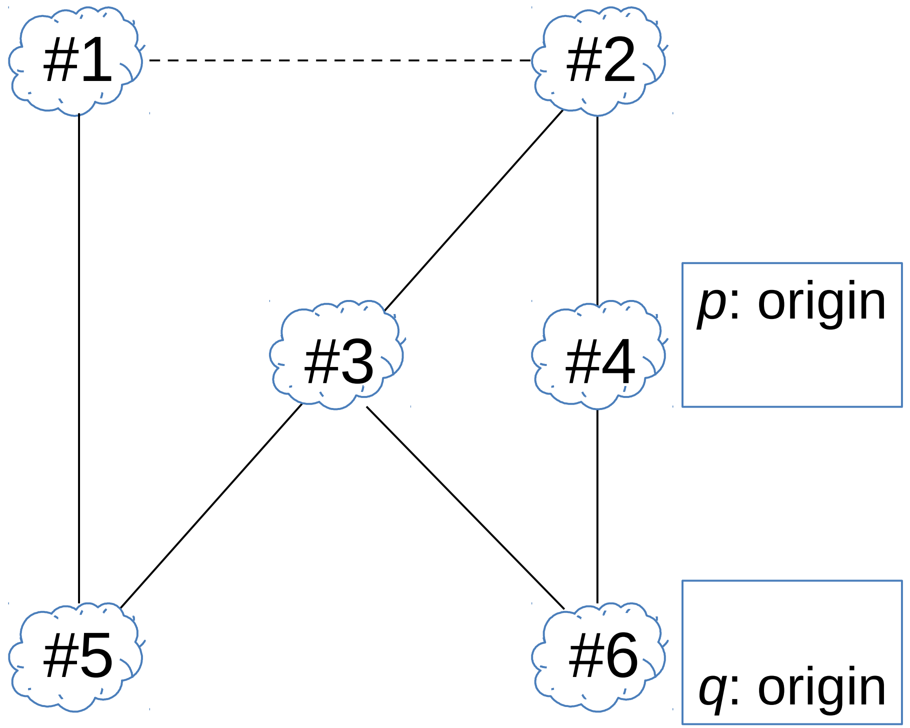
# Filtering strategy

- Locally filter the more specific prefixes when possible
  - no black holes
  - respect routing policies
- Use built-in incentives to filter locally
  - save on forwarding state
  - forward along best route (dictated by routing policies)
- *Exchange routing information with standard BGP*

# Providers, customers, and peers



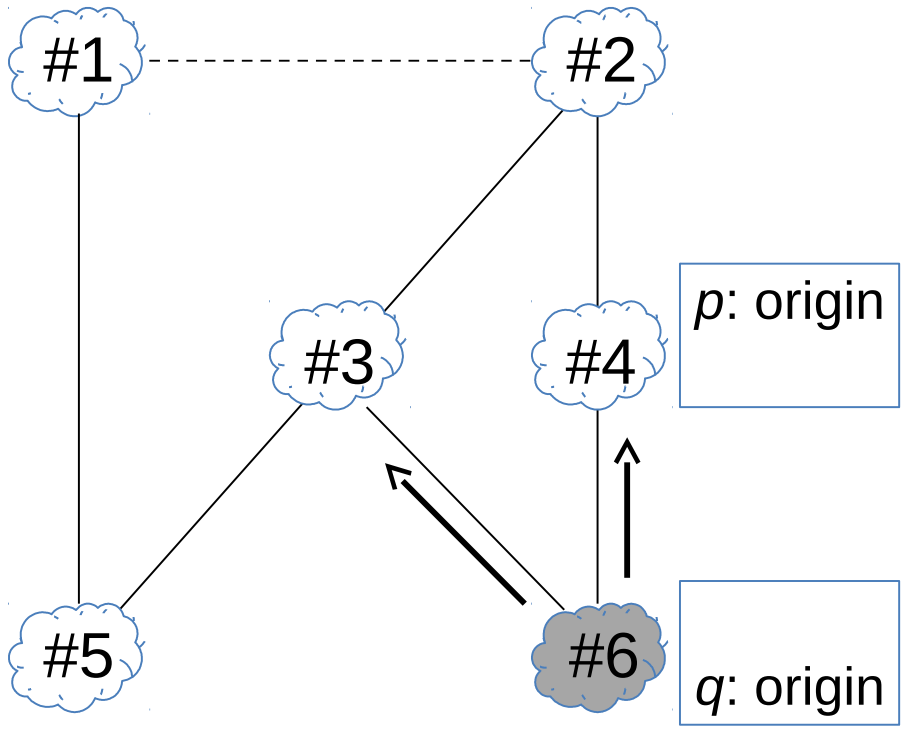
# Prefixes




#6 originates *q* (1.0.0.0/24); #4 originates *p* (1.0.0.0/16)

***q* more specific than *p***

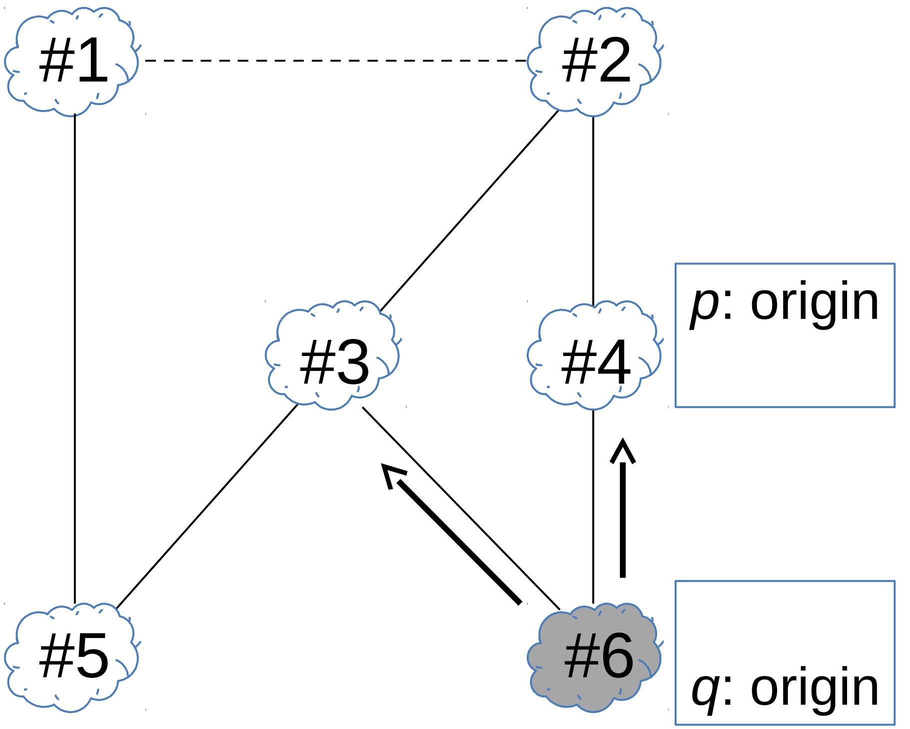
# Routes




**Route**
Association between a prefix and an attribute, from a totally ordered set of attributes

⟶
*q*-route
(route pertaining to *q*)

# Gao-Rexford routing policies




**route attributes:**

"customer"

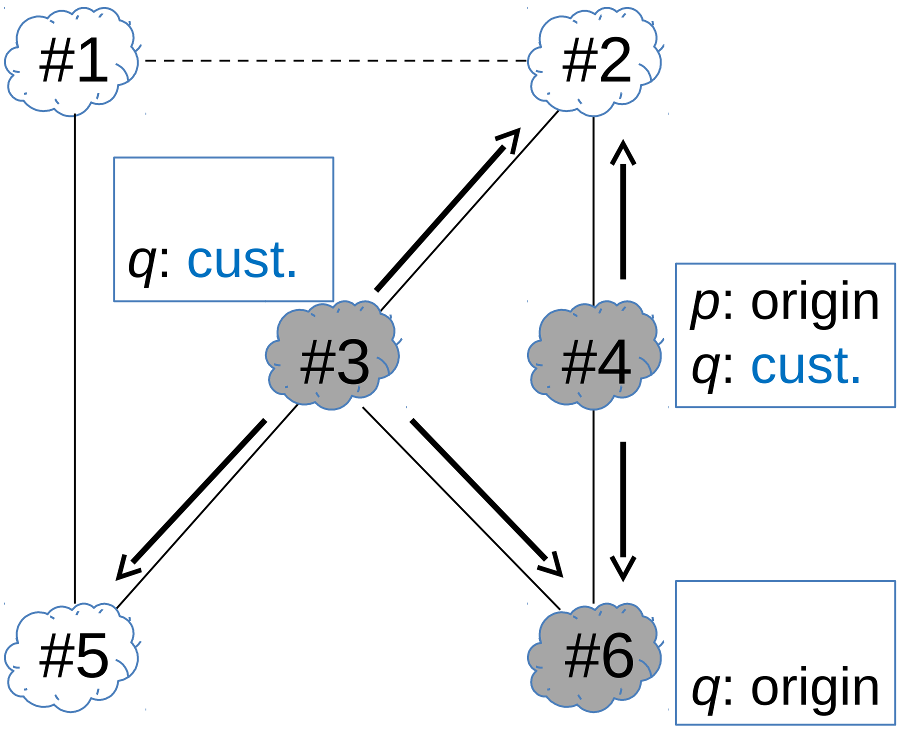
"peer"

"provider"


**preferences:** customer then peer then provider

**exportations:** all routes from customers; all routes to customers

# Gao-Rexford routing policies

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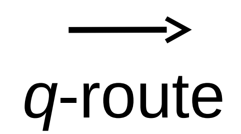


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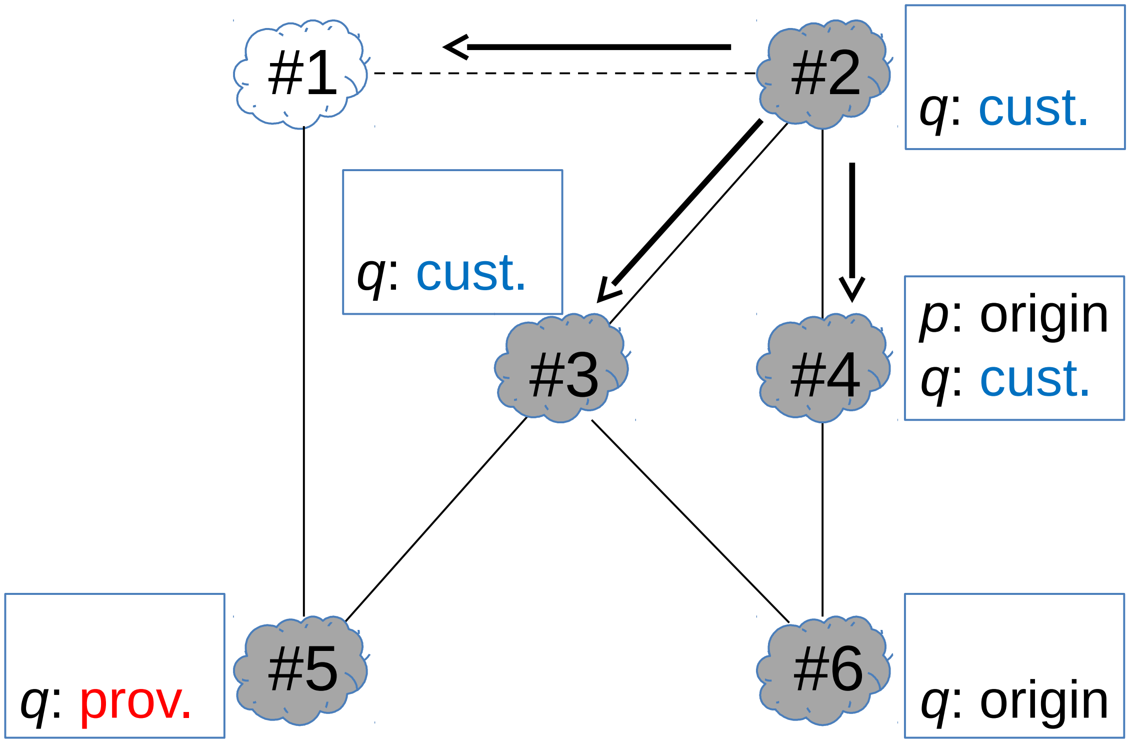
# Gao-Rexford routing policies




**route attributes:**

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→ *q*-route

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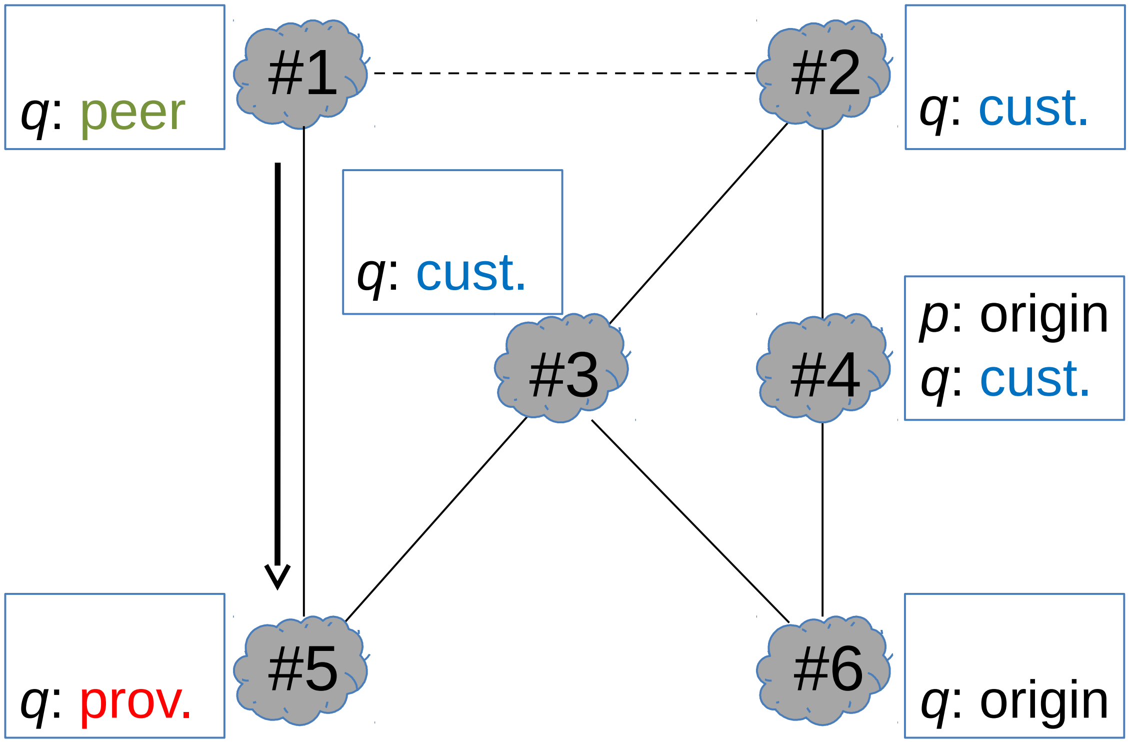
# Gao-Rexford routing policies




**route attributes:**

"customer"

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"provider"

⟶ *q*-route

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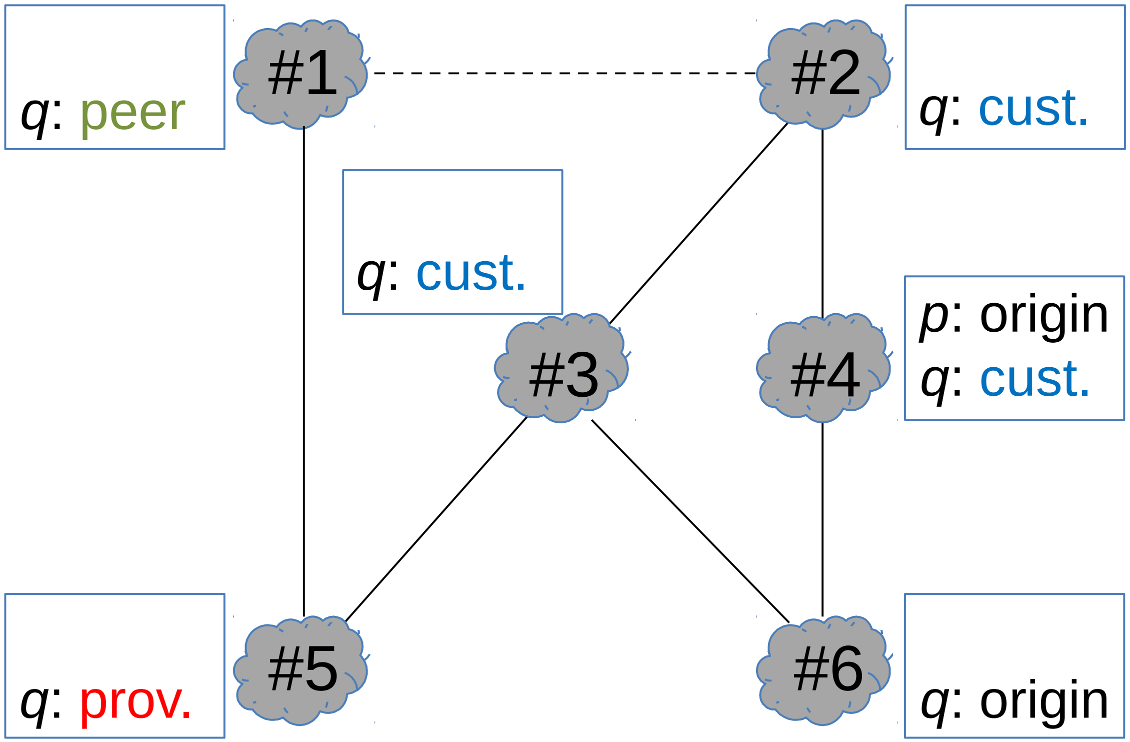
# Final state for prefix *q*



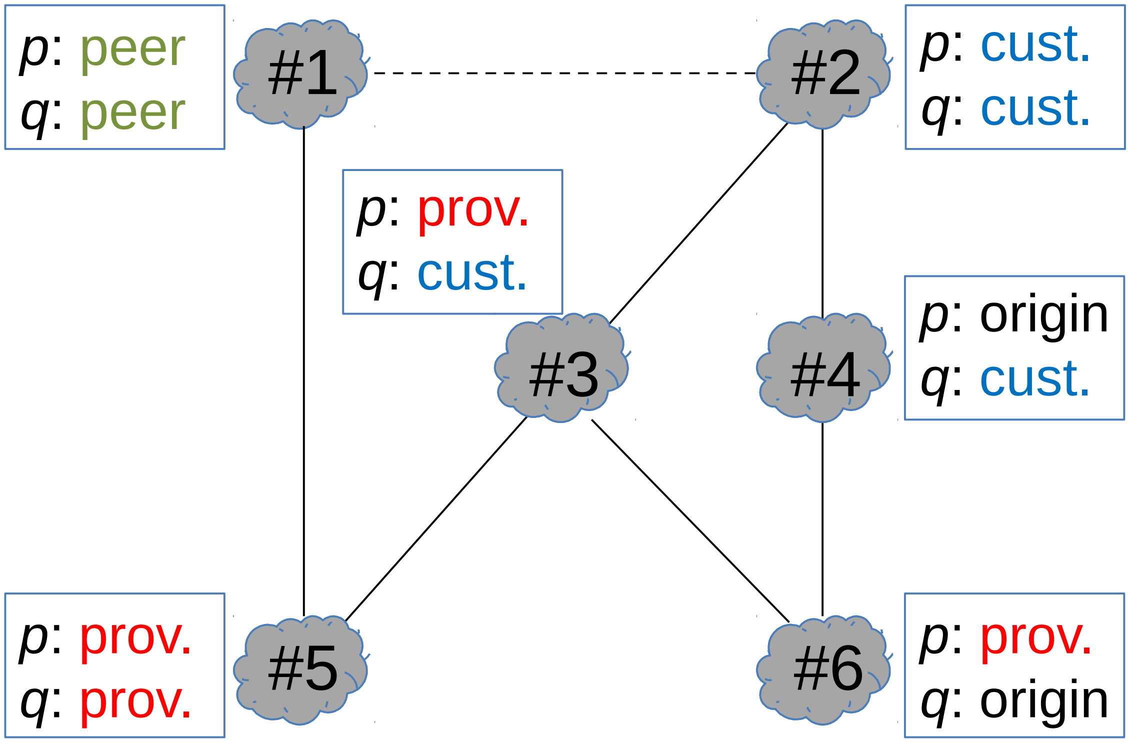

**route attributes:**

"customer"

"peer"

"provider"

# Final state for prefixes *q* and *p*




**route attributes:**

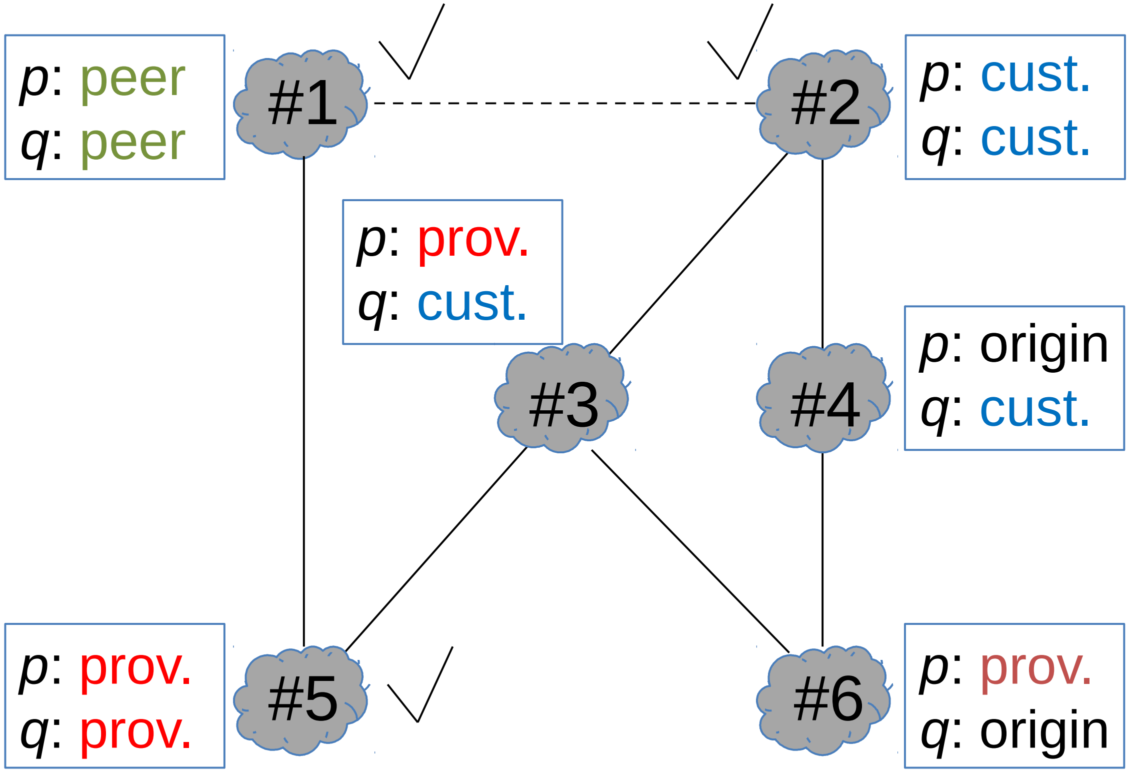
"customer"

"peer"

"provider"

**forwarding:** longest prefix match rule

# Filtering code (FC)



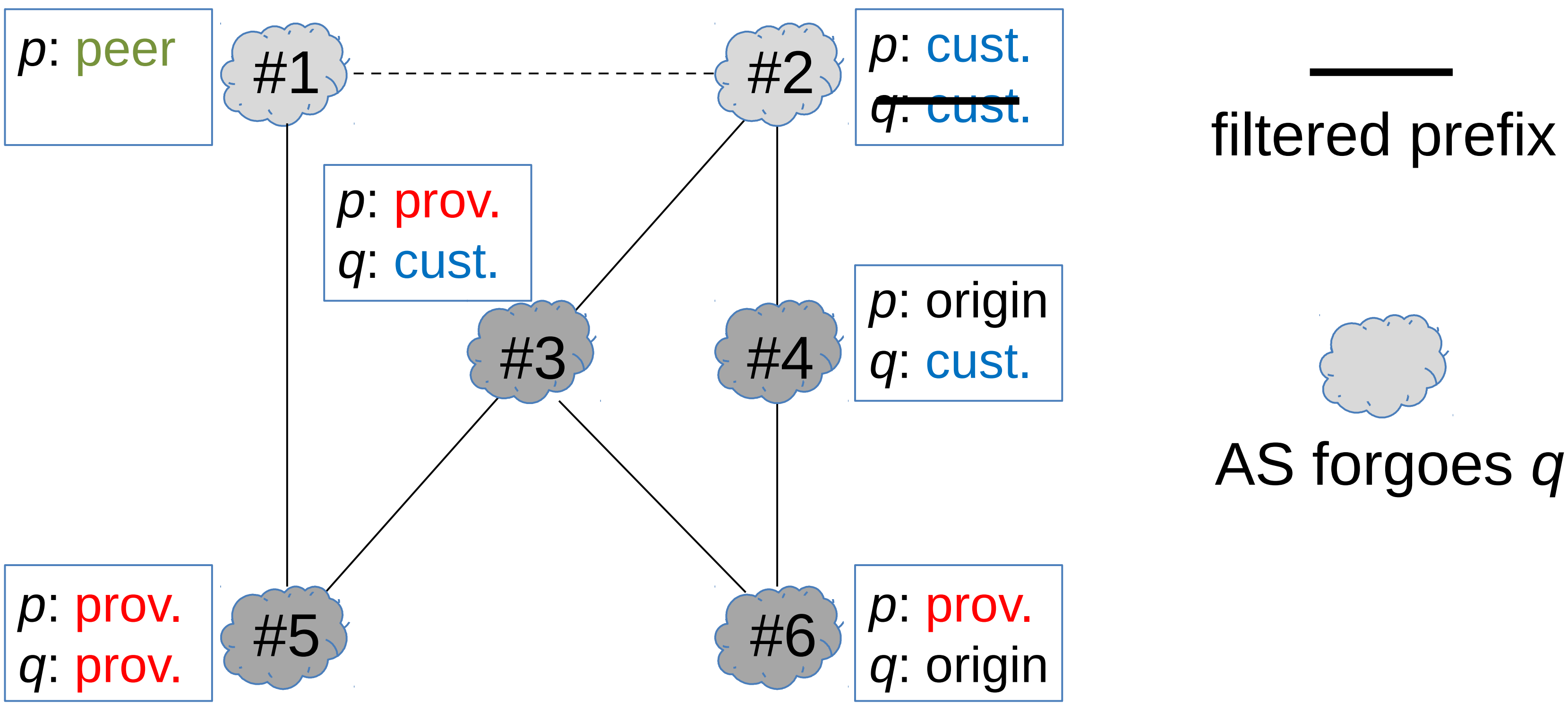

**Filtering Code (FC)**

Other than origin of *p*, in the presence of *p*, filter *q* if only if:

attribute of *p*-route
*same or preferred to*
attribute of *q*-route

√ASs that filter *q* upon execution of FC

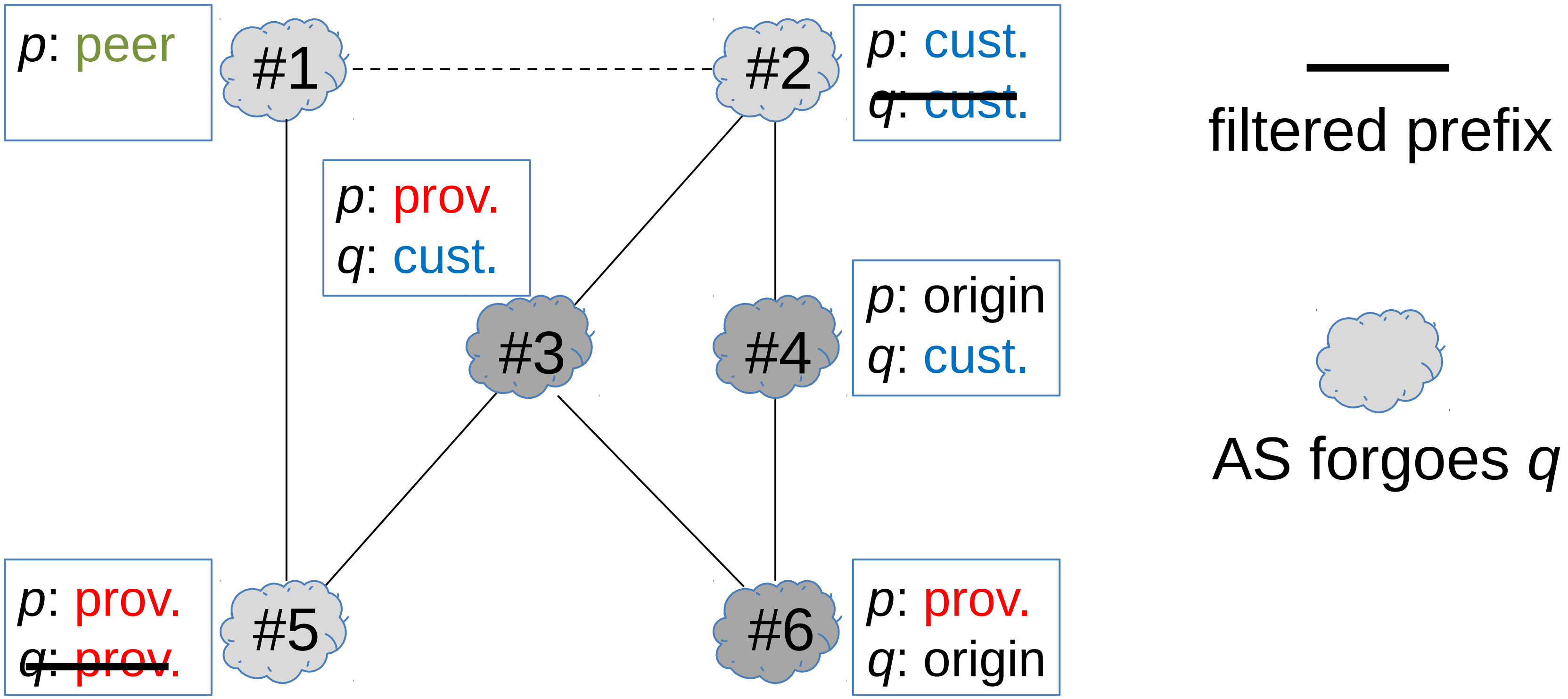
# AS 2 applies FC




AS 2 filters *q* ➡

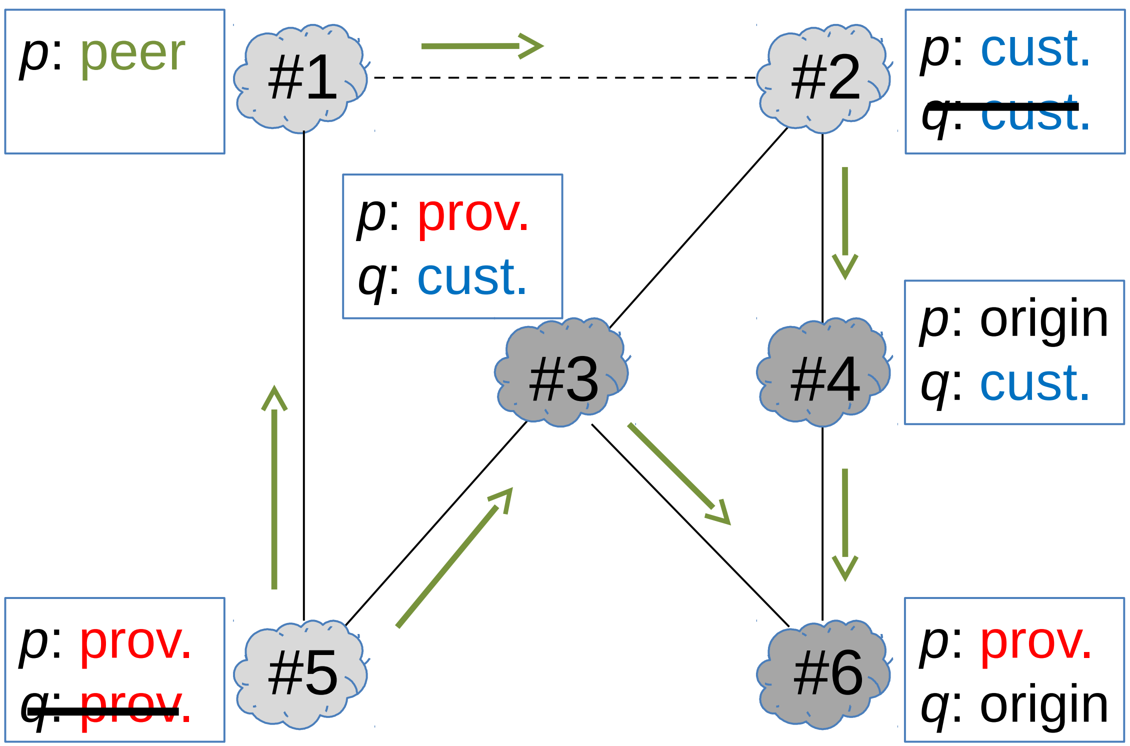
- AS 2 saves on forwarding state
- AS 1 is oblivious of *q*; it saves on forwarding and routing state

# All ASs apply FC




AS 1, AS 2, and AS 3 forgo *q* ➡ forwarding to *q* using less specific *p*

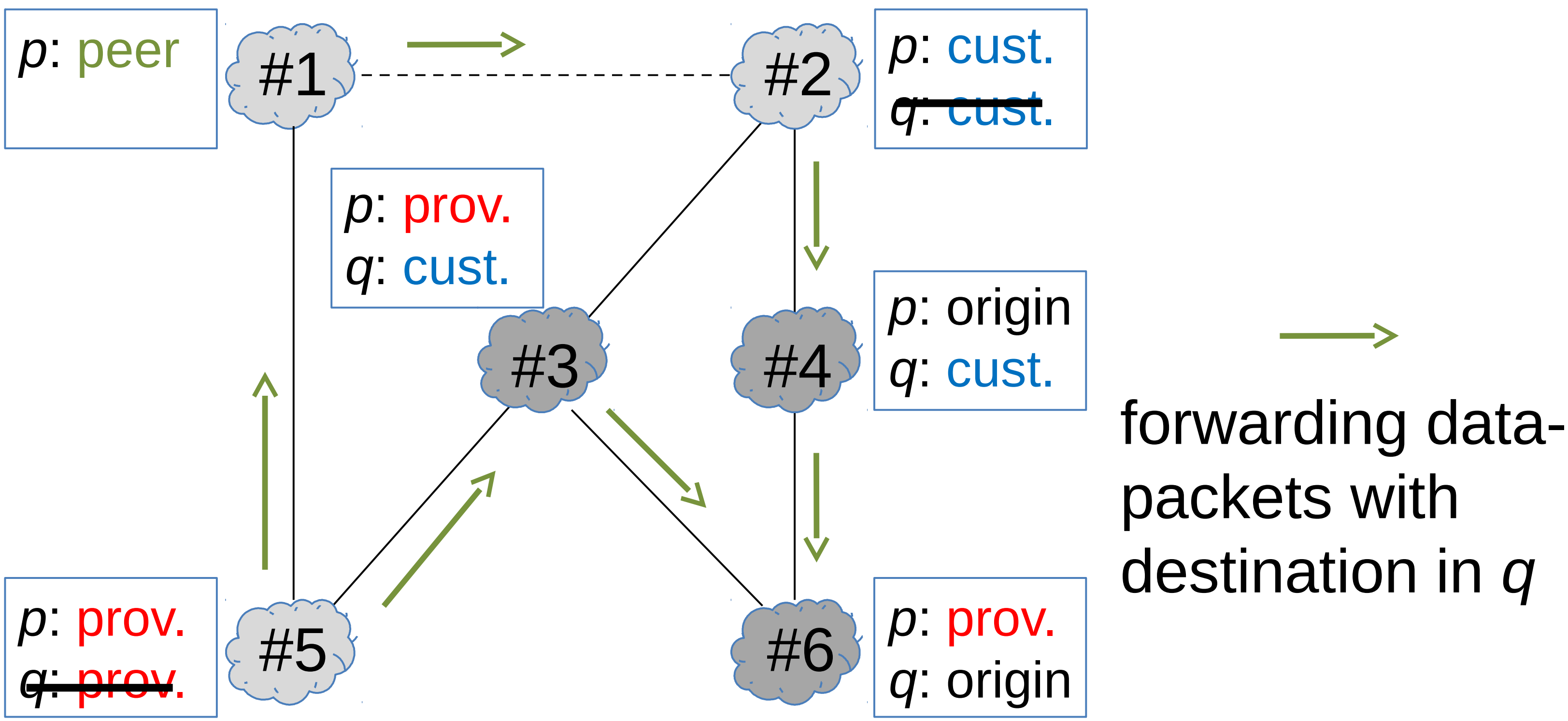
# Global property: correctness




forwarding data-packets with destination in *q*

**Correctness**: no routing anomalies (no black holes)

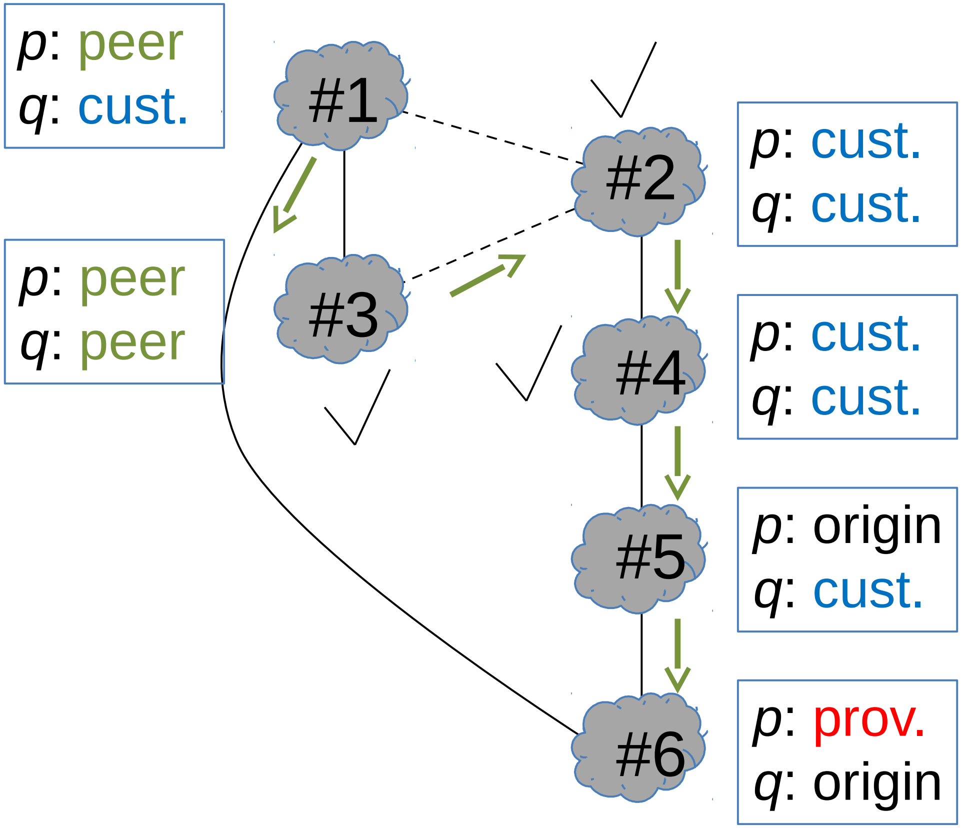
# Global property: route consistency




**Route consistency**: attribute of route used to forward data-packets is preserved

**Optimal route consistency**: set of ASs that forgo *q* is maximal

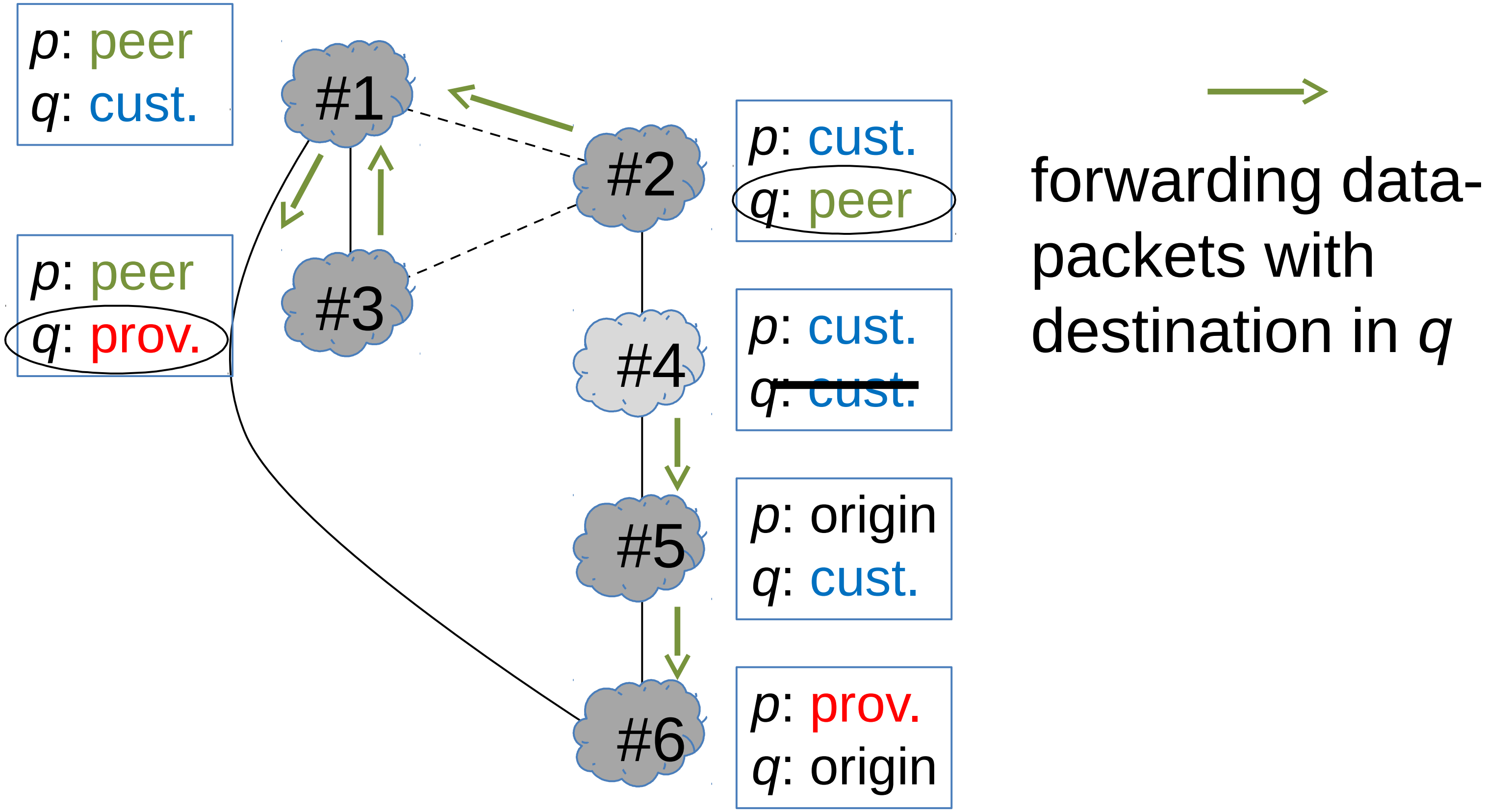
# Partial deployment




forwarding data-packets with destination in *q*

ASs that filter *q* upon execution of FC

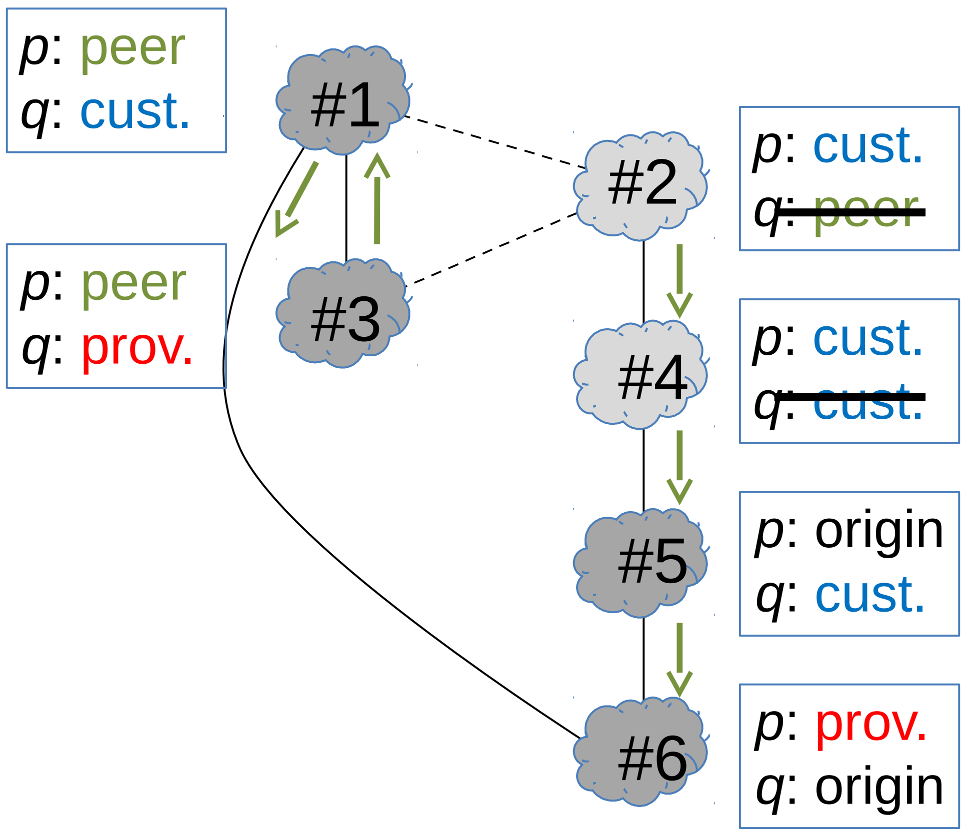
# Partial deployment: incentives




AS 2 (and AS 3) has a double incentive to apply the FC:

- saves on forwarding state
- improves attribute of route used to forward data-packets

# Partial deployment: incentives



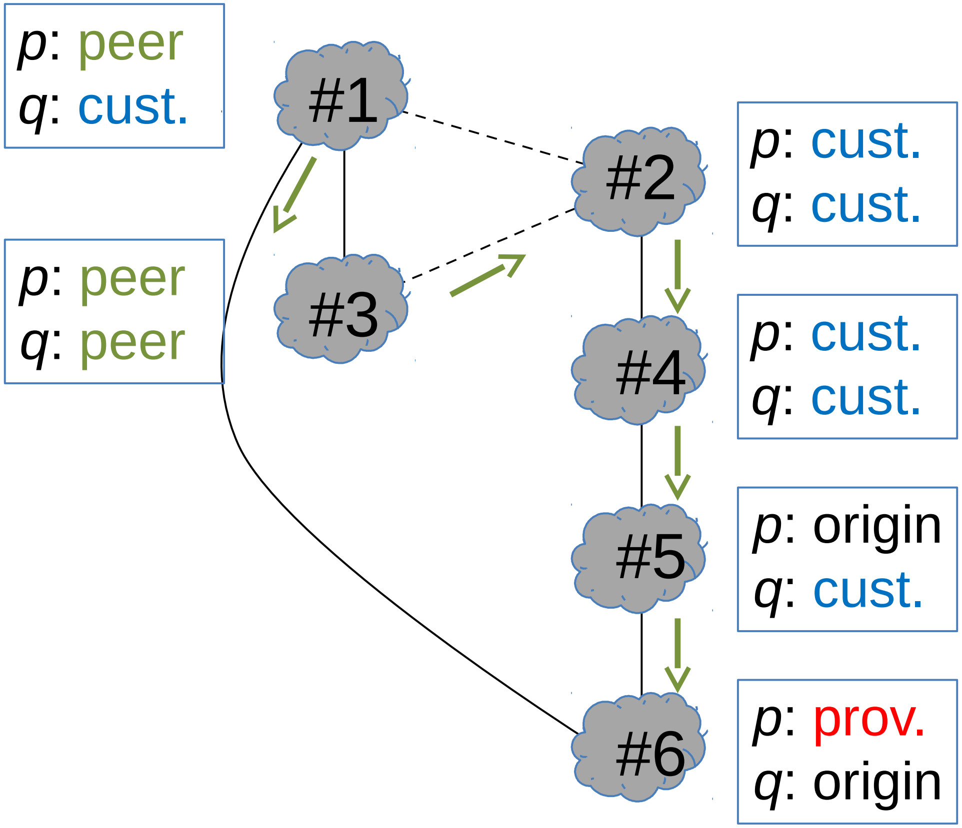

forwarding data-packets with destination in *q*

AS 2 applies FC

➡

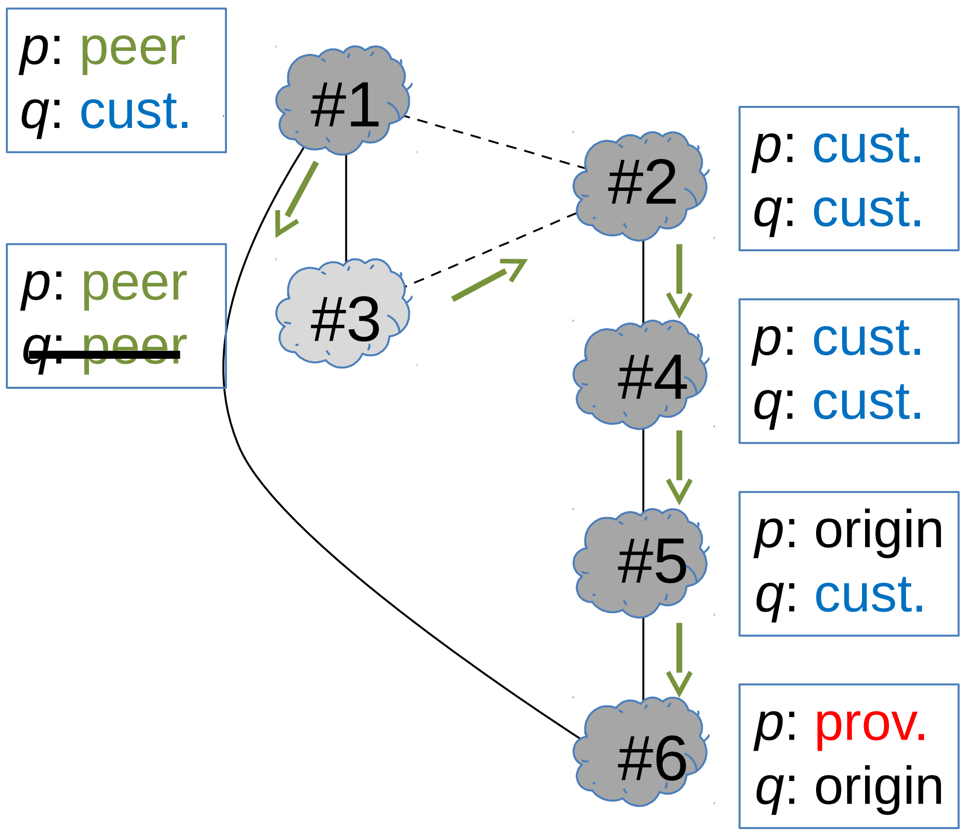
AS 2 reverts to forwarding data-packets with address in *q* to AS 4

# Partial deployment: route consistency




forwarding data-packets with destination in *q*

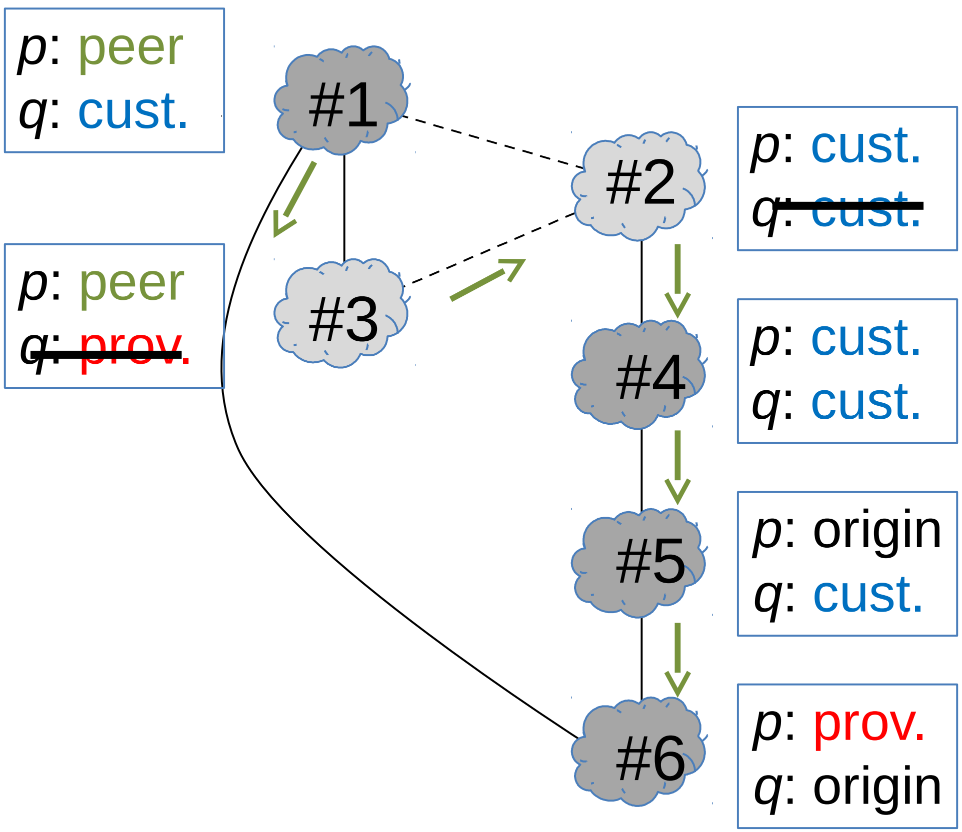
# Partial deployment: route consistency




forwarding data-packets with destination in *q*

**First to apply FC** are ASs that elect a peer or provider *q*-route

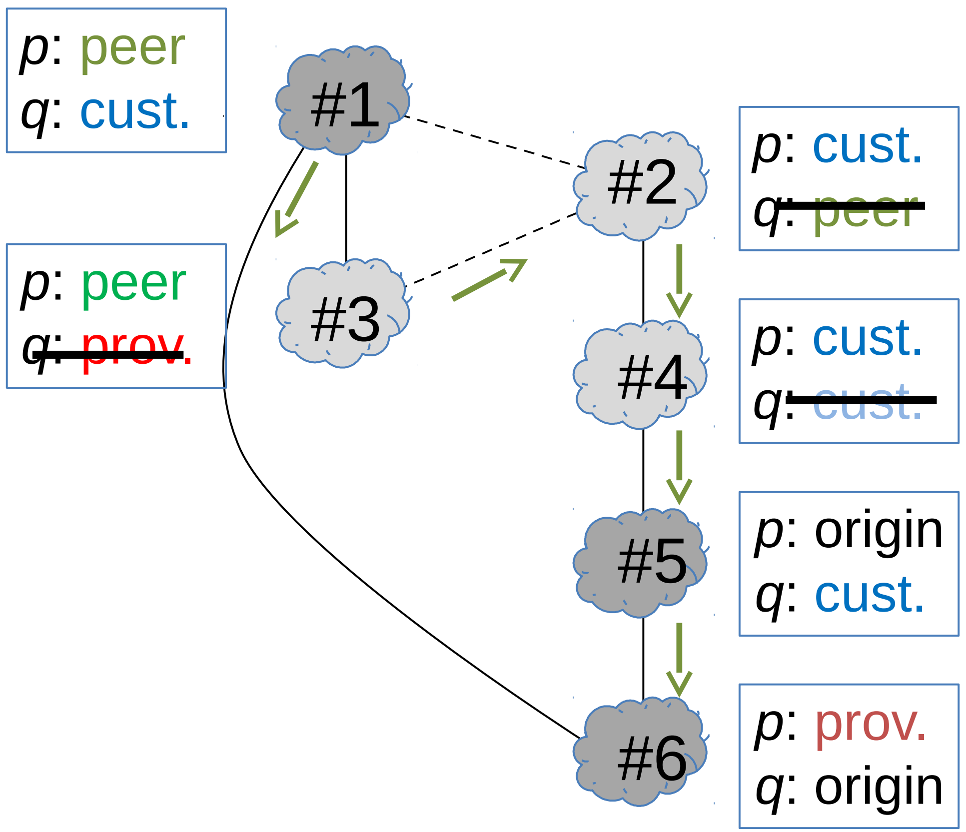
# Partial deployment: route consistency




forwarding data-packets with destination in *q*

**lext to apply FC** are ASs for which providers have already applied F

# Partial deployment: route consistency




→ forwarding data-packets with destination in *q*

**lext to apply FC** are ASs for which providers have already applied F

# Filtering strategy: general case

- Trees of prefixes learned from BGP
  - FC for a prefix in relation to the parent prefix
- Correctness
  - for the routing policies for which BGP is correct
- Route consistency (optimal and through partial deployment)
  - for *isotone* routing policies (includes Gao-Rexford)

**Optimal route consistency is not synonymous with *efficiency* (think shortest paths)**

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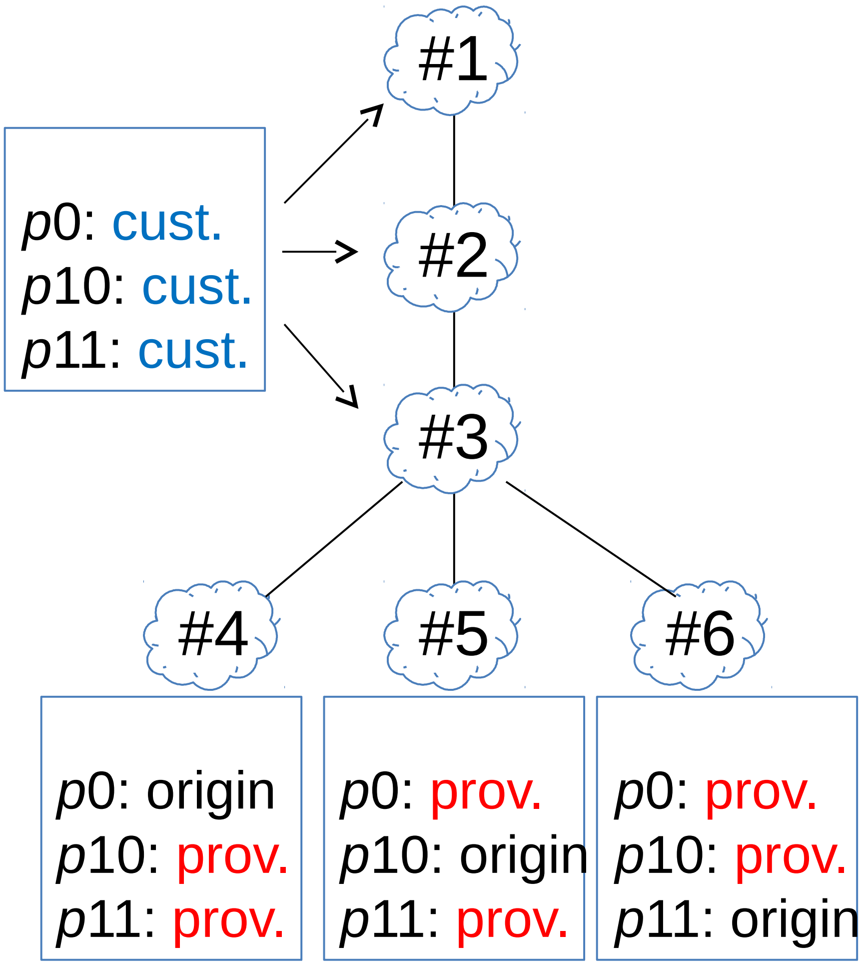
# Aggregation strategy

- Locally originate aggregation prefixes when beneficial
  - new address space is *not* created
  - allow filtering of provider-independent prefixes
  - self-organization when more than one AS originates the same aggregation prefix
- *Again, exchange routing information with standard BGP*

# Aggregation prefix

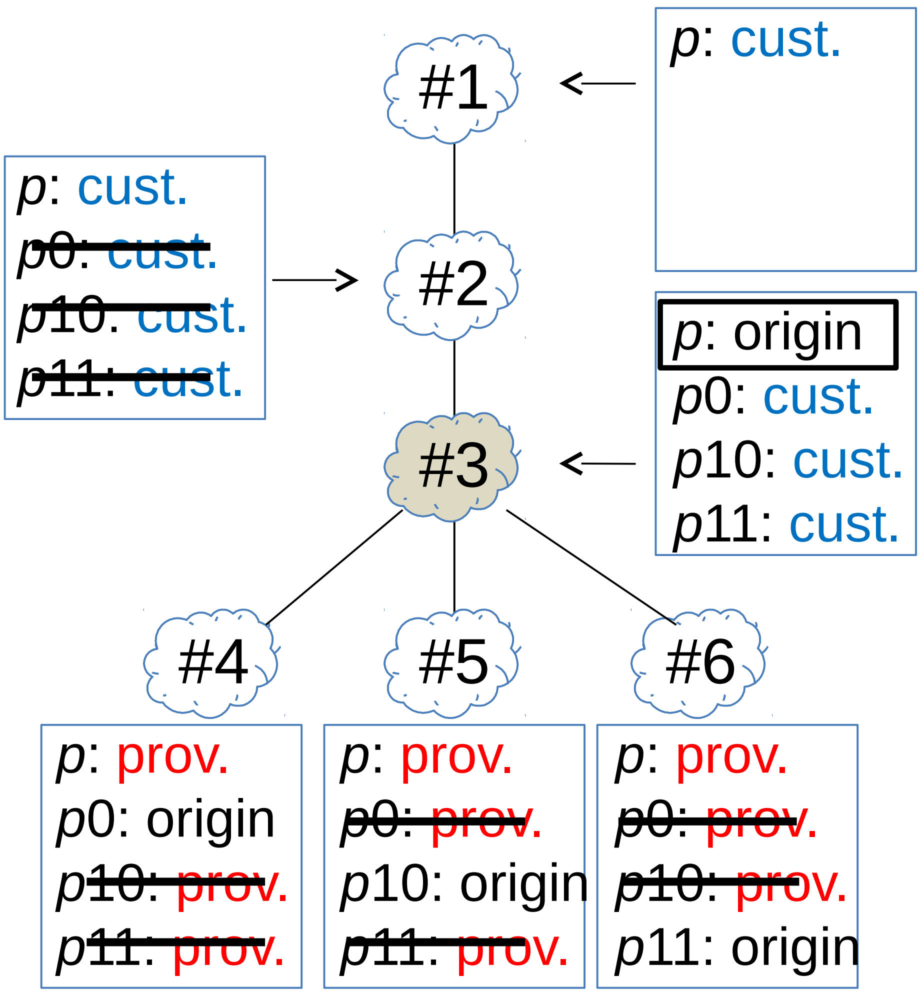



**Aggregation prefix**

1. no routable address space is created
2. at least two covered prefixes
3. customer route is elected for each of the covered prefixes

*p0* + *p*10 + *p*11= *p*; *p* is an aggregation prefix at AS 3

# AS 3 originates *p*




AS 1 is oblivious of *p*0, *p*10, and *p*11

AS 2 filters *p*0, *p*10, and *p*11

AS 4 filters *p*10 and *p*11
AS 5 filters *p*0 and *p*11
AS 6 filters *p*0 and *p*10

# Aggregation strategy: general case

- Trees of prefixes learned from BGP
  - aggregation prefixes cover parentless prefixes
- Self-organization
  - for the routing policies for which BGP is correct
- Optimal origins
  - for *isotone* routing policies (includes Gao-Rexford)

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# Data-sets

- Annotated topology (CAIDA, Feb. 2015)
  - ~50K ASs; ~42K stub ASs
  - ~94K provider links; ~94K customer links; 180K peer links
- IPv4-prefixes-to-ASs mapping (CAIDA, Feb. 2015)
  - ~530K prefixes
  - ~270K parentless prefixes
  - ~210K prefixes have same origin AS as parent

# FIB filtering efficiency: definition

Normalized amount of reduction brought by DRAGON to the forwarding tables of an AS

$$\textbf{FilterEff} = \frac{\#\,(\text{FIB entries BGP}) \; - \; \#\,(\text{FIB entries DRAGON})}{\#\,(\text{FIB entries BGP})}$$

# FIB filtering efficiency: results

| | **Basic DRAGON**<br>filtering | **Full DRAGON**<br>filtering & aggregation |
|---|---|---|
| **Min.** FilterEff | **47%** | |
| **% of ASs with at least Min.** FilterEff | **100%** | |
| **Max.** FilterEff | **49%** | |
| **% of ASs attaining Max.** FilterEff | **87%** | |

# FIB filtering efficiency: results

| | **Basic DRAGON** filtering | **Full DRAGON** filtering & aggregation |
|---|---|---|
| **Min.** FilterEff | **47%** | **69%** |
| **% of ASs with at least Min.** FilterEff | **100%** | **100%** |
| **Max.** FilterEff | **49%** | **79%** |
| **% of ASs attaining Max.** FilterEff | **87%** | **87%** |

# Outline

- Scalability: global view
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# Conclusions

- DRAGON is a BGP add-on to scale the Internet routing system
- DRAGON can be deployed incrementally
- DRAGON reduces the amount of forwarding state by approximately 80%
- DRAGON is – more fundamentally – a solid framework to reason about route aggregation

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Thank you!